OPEN-FILE REPORT 98-22

SEISMIC HAZARD EVALUATION OF THE REDONDO BEACH 7.5-MINUTE QUADRANGLE, LOS ANGELES COUNTY, CALIFORNIA

1998

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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PREFACE

With the increasing public concern about the potential for destructive earthquakes in northern and southern California, the State Legislature passed the Seismic Hazards Mapping Act in 1990. The purpose of the Act is to protect the public from the effects of strong ground shaking, liquefaction, landslides or other ground failure, and other hazards caused by earthquakes. The program and actions mandated by the Seismic Hazards Mapping Act closely resemble those of the Alquist-Priolo Earthquake Fault Zoning Act (which addresses only surface fault-rupture hazards) and are outlined below:

1. **The State Geologist** is required to delineate the various "seismic hazard zones."

2. **Cities and Counties**, or other local permitting authorities, must regulate certain development "projects" within the zones. They must withhold the development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans.

3. **The State Mining and Geology Board (SMGB)** provides additional regulations, policies, and criteria to guide cities and counties in their implementation of the law. The SMGB also provides criteria for preparation of the Seismic Hazard Zone Maps (Web site http://www.consrv.ca.gov/dmg/shezp/zoneguid/) and for evaluating and mitigating seismic hazards.

4. **Sellers (and their agents)** of real property within a mapped hazard zone must disclose at the time of sale that the property lies within such a zone.

As stated above, the Act directs the State Geologist, through the Division of Mines and Geology (DMG) to delineate seismic hazard zones. Delineation of seismic hazard zones is conducted under criteria established by the Seismic Hazards Mapping Act Advisory Committee and its Working Groups and adopted by the California SMGB.

The Official Seismic Hazard Zone Maps, released by DMG, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available from:

> BPS Reprographic Services
> 149 Second Street
> San Francisco, California 94105
> (415) 512-6550

Seismic Hazard Evaluation Reports, released as Open-File Reports (OFR), summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These Open-File Reports are available for reference at DMG offices in Sacramento,

San Francisco, and Los Angeles. Copies of the reports may be purchased at the Sacramento, Los Angeles, and San Francisco offices. In addition, the Sacramento office offers prepaid mail order sales for all DMG OFRs. **NOTE: The Open-File Reports are not available through BPS Reprographic Services.**

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Seismic Hazard Evaluation Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that the 1) process for zoning liquefaction hazards remain unchanged and that 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Evaluation Report summarizes the development of the hazard zone map for each area. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historic high-water-table information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Redondo Beach 7.5-minute Quadrangle (scale 1:24,000).

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Redondo Beach 7.5-Minute Quadrangle, Los Angeles County, California

By
Richard B. Greenwood

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Redondo Beach 7.5-minute Quadrangle (scale 1:24,000). This section and Section 2 addressing earthquake-induced landslides, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazards zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Liquefaction-induced ground failure has historically been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated granular sediments within the upper 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, as well as in the Redondo Beach Quadrangle.

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils is generally confined to areas covered by Quaternary sedimentary deposits. Such areas consist mainly of alluviated valleys, floodplains, and canyon regions. The evaluation is based on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth data, most of which are gathered from a variety of sources. The quality of the data used varies. Although selection of data used in this evaluation was rigorous, the state of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth and thickness of liquefiable sediments, depth to ground water, rate of drainage, slope gradient, proximity to free-face conditions, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to determine the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction potential, opportunity, susceptibility, and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The onshore portion of the Redondo Beach Quadrangle covers an area of about 13 square miles in southwestern Los Angeles County. The low-lying topography in the northeastern corner includes parts of the coastal cities of Hermosa Beach, Manhattan Beach, Redondo Beach and Torrance. The southeastern corner of the map includes the western portion of the Palos Verdes Peninsula where parts of the cities of Palos Verdes Estates, Rancho Palos Verdes, and Rolling Hills Estates are located.

The quadrangle includes the shoreline of Santa Monica Bay from City of Redondo Beach southward to the Palos Verdes Peninsula. Coastal cities were developed on active and inactive coastal sand dunes, which locally required extensive placement of artificial fills in the Redondo Beach area. The topography of the elevated Palos Verdes Peninsula is characterized by a series of stair step-like Pleistocene wave-cut marine terraces that are generally covered by a non-marine veneer over thin marine terrace deposits. The lowland areas of the Redondo Beach Quadrangle are covered with modern beach sands and late Pleistocene to Holocene dune sand deposits.

Access along the northern coastal section of the quadrangle is provided by Pacific Coast Highway (State Highway 1). Palos Verdes Drive and Hawthorne Boulevard provide access on the Palos Verdes Peninsula.

GEOLOGIC CONDITIONS

Surface Geology

A digital map obtained from the U.S.Geological Survey (Tinsley, unpublished) was used as a base to prepare a geologic map of the Redondo Beach Quadrangle for this project. Additional detail was added from a digital map prepared by the Southern California Areal Mapping Project (SCAMP, unpublished) and the California Division of Mines and Geology (Bezore and others, unpublished), which was compiled primarily from Poland and others (1959). Quaternary geologic contacts received minor modifications in accordance with information taken from older 1:20,000-scale U.S. Geological Survey topographic maps (Torrance, 1934), the 1:62,500-scale Redondo Quadrangle (1896; 1944), and an older regional soils map (Nelson and others, 1919). Stratigraphic nomenclature was revised to follow the format developed by SCAMP (Morton and Kennedy, 1989). The revised geologic map that was used in this study of liquefaction susceptibility is included as Plate 1.1.

The oldest Quaternary geologic unit mapped in the Redondo Beach Quadrangle is the Pleistocene San Pedro Formation (Qsp), a predominantly marine sand and gravel deposit exposed in the Palos Verdes Peninsula. A detailed description of the bedrock geology of the Palos Verdes Peninsula is presented in Section 2.

Woodring and others (1946) recognized the early-Pleistocene San Pedro Sand (Qsp) as the oldest Quaternary geologic unit within the Redondo Beach Quadrangle. The San Pedro Formation is a massive, poorly consolidated, light brown, marine sand deposit exposed in the Palos Verdes Hills. Woodring and others (1946) also mapped multiple levels of Pleistocene marine terraces with dense silty sand terrace deposits (Qter/Ooa) in the Palos Verdes Hills. Modern eolian deposits (Qe) form a quarter- to one-half-mile-wide strip along the coastline adjacent to the modern beach. The eolian deposits are composed of very well-sorted, fine- to medium-grained sand that rapidly grade into Pleistocene moderately dense silty sand of older eolian deposits (Qoe). Local drainages are incised and filled with younger alluvium, consisting of soft, locally-derived sandy silt and sandy clay of younger alluvium (Qya2). Modern beach deposits (Qm), which consist of well-sorted, medium- to coarse-grained sand, form the shoreline of Santa Monica Bay.

Subsurface Geology and Geotechnical Characteristics

The liquefaction analysis for the Redondo Beach Quadrangle focused on areas of artificial fill and beach sands. Data from seven boreholes were collected for this study at the Regional Water Quality Control Board. Also reviewed were DMG files of seismic reports for hospitals, school site files from the State Architect’s Office, and local water well logs from the California Department of Water Resources. Geotechnical data, particularly SPT blow counts, from environmental studies are sometimes less reliable however, due to the use of non-standard equipment and incomplete reporting of procedures.

Data from borehole logs were entered into the DMG Geographic Information System (GIS) database. Locations of all exploratory boreholes entered into the database for consideration in this investigation are shown on Plate 1.2.

Descriptions of characteristics of geologic units are given below. These descriptions are necessarily generalized, but give the most commonly encountered characteristics of the units (see Table 1.1).

San Pedro Sand (Qsp)

The San Pedro Sand was mapped by Woodring and others (1946) on the Palos Verdes Peninsula. Lower Pleistocene San Pedro Sand is typically composed of cross-bedded to massive sand and silty sand.

Older eolian deposits (Qoe) and marine terrace deposits (Qter/Qoa)

Late Pleistocene eolian deposits comprise most of the eastern Redondo Beach Quadrangle. These older, largely stabilized dune sands form a veneer over late Pleistocene terrace surfaces. Ground water is deep throughout this area, so no extensive effort was made to collect subsurface data. They are generally described as dense to very dense sands and silty sands. Late Pleistocene marine terrace deposits (Qter), mapped in places as Qoa, generally consist of silty sand with local gravels that are found throughout the Palos Verdes Peninsula.

Modern eolian deposits (Qe)

Modern eolian deposits are composed of very well sorted, fine- to medium-grained sand and rapidly grade into Pleistocene moderately dense silty sand of older eolian deposits (Qoe).

Younger alluvium (Qya2)

Younger alluvial deposits consist of locally derived soft silt and clay with some loose to moderately dense silty sand and sand.

Modern beach deposits (Qm)

Modern beach deposits (Qm), which consist of well sorted, medium- to coarse-grained sand, form the shoreline of Santa Monica Bay.

Artificial fill (af)

Artificial fill in the Redondo Beach Quadrangle consists of undifferentiated new and old fills associated with development of the greater Redondo Beach Harbor complex.

Geologic Map Unit	Material Type	Consistency	Liquefaction Susceptibility
af, artificial fill	sand, silty sand	soft to dense	high
Qm, modern beach deposits	sand	soft	high
Qya2, younger alluvial deposits	silty sand, and sand	soft to moderately dense	high to moderate
Qe, modern eolian deposits	sand	soft	moderate to low
Qoe, older dune sand	silty sand and sand	moderately dense-very dense	low
Qter/Qoa, older marine terrace	silty sand, minor gravel	dense-very dense	low
Qsp, San Pedro Sand	sand, silty sand, minor gravel	loose to moderately dense	low

Table 1.1. General Geotechnical Characteristics and Liquefaction Susceptibility of Younger Quaternary Units.

GROUND-WATER CONDITIONS

A ground-water evaluation of alluviated areas was performed in order to determine historically shallowest ground-water levels in the Redondo Beach Quadrangle. Areas characterized by historical ground water or perched water with depths of less than 40 feet are considered for the purposes of liquefaction hazard zoning. The evaluation was based on first-encountered water levels encountered in geotechnical boreholes and selected water wells. Turn-of-the-century water-well logs and data (Mendenhall, 1905) were also reviewed but were generally found to be inadequate for the purposes of this study. As noted by Poland and others (1959, p. 90): recent topographic maps differ considerably from the land surface modeled by the 25-foot contour interval of the 1894 base map.

Mendenhall (1905) contoured all available water levels--from all aquifers. For the current evaluation the depths to first-encountered water free of piezometric influences were plotted and contoured on a map showing depths to historically shallowest ground water (Plate 1.2). This map was digitized and used for the liquefaction analysis.

PART II

EVALUATING LIQUEFACTION POTENTIAL

Liquefaction occurs in water-saturated sediments during moderate to great earthquakes. Liquefied sediments are characterized by a loss of strength and may fail, causing damage to buildings, bridges, and other such structures. A number of methods for mapping liquefaction hazard have been proposed; Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of susceptibility units, and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce liquefaction potential. Liquefaction susceptibility is a function of the capacity of sediments to resist liquefaction and liquefaction opportunity is a function of the seismic ground shaking intensity. The application of the Seed Simplified Procedure (Seed and Idriss, 1971) for evaluating liquefaction potential allows a quantitative characterization of susceptibility of geologic units. Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for mapping liquefaction hazards in the Los Angeles region. The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985), combining geotechnical data analyses, and geologic and hydrologic mapping, but follows criteria adopted by the California State Mining and Geology Board (in press).

LIQUEFACTION OPPORTUNITY

According to the criteria adopted by the California State Mining and Geology Board (in press), liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for ground shaking strong enough to generate liquefaction. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period. The earthquake magnitude is the magnitude that contributes most to the acceleration.

For the Redondo Beach Quadrangle, peak accelerations of 0.39 g to 0.55 g resulting from an earthquake of magnitude 7.1 were used for liquefaction analyses. The PGA and magnitude values were derived from maps prepared by Petersen and others (1996) and

Cramer and Petersen (1996), respectively. See the ground motion portion (Section 3) of this report for further details.

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of soils to loss of strength when subjected to ground shaking. Primarily, physical properties and conditions of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance. These properties and conditions are correlated with geologic age and environment of deposition. With increasing age of a deposit, relative density may increase through cementation of the particles or the increase in thickness of the overburden sediments. Grain size characteristics of a soil also influence susceptibility to liquefaction. Sands are more susceptible than silts or gravels, although silts of low plasticity are treated as liquefiable in this investigation. Cohesive soils are generally not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in lower liquefaction susceptibility generally result in higher penetration resistances to the soil sampler. Different blow count corrections are used for silty sand and nonplastic silt than for clean sand (Seed and others, 1985). Therefore, blow count or cone penetrometer values are a useful indicator of liquefaction susceptibility.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (more likely to liquefy). Soils that lack resistance (susceptible soils) are typically saturated, loose sandy sediments. Soils resistant to liquefaction include all soil types that are dry or sufficiently dense.

DMG’s map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil-property and soil-condition factors such as type, age, texture, color, and consistency, along with historic depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, findings can be related to the map units. DMG’s qualitative susceptible soil inventory is summarized on Table 1.1.

San Pedro Sand (Qsp)

The lower Pleistocene San Pedro Sand is typically composed of cross-bedded to massive sand and silty sand. As this unit predates the late Pleistocene age restrictions of the liquefaction susceptibility criteria, low liquefaction susceptibility is assigned.

Older eolian deposits (Qoe) and marine terrace deposits (Qter/Qoa)

Older eolian and marine terrace deposits are composed of dense to very dense sands and silty sands. Liquefaction susceptibility of these units is low.

Modern eolian deposits

Modern eolian deposits are composed of very well sorted, fine- to medium-grained sand that is assumed to be well drained. Liquefaction susceptibility of this unit is low to moderate.

Younger alluvium (Qya2)

Younger alluvial deposits consist of locally derived soft silt and clay with some loose to moderately dense silty sand and sand. Liquefaction susceptibility of this unit, where saturated, is moderate to high.

Modern beach deposits

Modern beach deposits, which consist of well-sorted, medium- to coarse-grained sand, form the shoreline of Santa Monica Bay. Liquefaction susceptibility of this unit is high.

Artificial fill (af)

Artificial fills commonly overlie young beach sand deposits. Because the artificial fills are usually too thin to affect the liquefaction hazard, and the underlying beach sand deposits have a high liquefaction susceptibility, fills are assumed to have a high susceptibility to liquefaction.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; Seed and Harder, 1990; Youd and Idriss, 1997). This procedure calculates soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR) based on standard penetration test (SPT) results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The factor of safety (FS) relative to liquefaction is: FS=CRR/CSR. FS, therefore, is a quantitative measure of liquefaction potential. Generally, a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, indicates the presence of potentially liquefiable soil. DMG uses FS, as well as other considerations such as slope, free face conditions, and thickness and depth of potentially liquefiable soil, to construct liquefaction potential maps, which then directly translate to Zones of Required Investigation.

Six borehole logs compiled for this study had blow counts from standard penetration tests or from tests that could be converted to SPTs. Few included all of the required information (SPTs, density, water content, percentage of silt and clay size grains) for a complete Seed Simplified analysis. For those boreholes where SPTs were recorded, the liquefaction analysis was conducted either using data from that borehole or if the other data were lacking, extrapolated from nearby boreholes in similar materials.

LIQUEFACTION ZONES

Criteria for Zoning

The areas underlain by late Quaternary geologic units were included in liquefaction zones using the criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the California State Mining and Geology Board (in press). Under those criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historic earthquakes.

2. All areas of uncompacted fills containing liquefaction susceptible material that are saturated, nearly saturated, or may be expected to become saturated.

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable.

4. Areas where existing geotechnical data are insufficient.

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historic high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (between 11,000 years and 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historic high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria for liquefaction zoning in the Redondo Beach Quadrangle is summarized below.

Areas of Past Liquefaction

In the Redondo Beach Quadrangle, major effects attributed to liquefaction were noted in Redondo Beach at King Harbor following the 1994 Northridge earthquake. Liquefaction-induced lateral spreading and differential settlement severely damaged the Mole B marina facilities (Stewart and others, 1994) and (Kerwin and Stone, 1997; see Plate 1.2).

Artificial Fills

In the Redondo Beach Quadrangle artificial fill consists of engineered fill primarily around the King Harbor area. The engineered fills are generally too thin to have an impact on liquefaction but overlie beach sand deposits that are susceptible to liquefaction. Areas underlain by artificial fill have been included in liquefaction hazard zones.

Areas with Existing Geotechnical Data

The San Pedro Sand (Qsp), marine terrace deposits (Qter), and older eolian deposits (Qoe) in the Redondo Beach Quadrangle have dense consistencies and deep ground water was encountered in many of the areas underlain by these units. Accordingly, these geologic units have not been included in a liquefaction hazard zone.

Younger eolian deposits (Qe) are typically very thin and permeable, and therefore, unsaturated. They are not included in liquefaction hazard zones.

Younger alluvial deposits (Qya2) commonly have layers of loose silty sand or sand. Where these deposits are saturated, they are generally included in a liquefaction hazard zone.

Modern beach deposits (Qm) are typically loose saturated sand. They are included in liquefaction hazard zones.

ACKNOWLEDGMENTS

The author would like to thank the staff at the California Department of Transportation (Caltrans), and the Los Angeles Regional Water Quality Control Board for their assistance in the collection of subsurface borehole data. John Tinsley of the U.S. Geological Survey graciously shared information from his extensive files of subsurface geotechnical data for this area and provided a digital Quaternary map of the quadrangle. At DMG, special thanks to Bob Moskovitz, Teri McGuire, Barbara Wanish, and Scott Shepherd for their GIS operations support, and to Barbara Wanish for designing and plotting the graphic displays associated with the liquefaction zone map and this report.

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SECTION 2

EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Redondo Beach 7.5-Minute Quadrangle, Los Angeles County, California

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Redondo Beach 7.5-minute Quadrangle (scale 1:24,000). This section and Section 1 addressing liquefaction, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Landslides triggered by earthquakes have historically been a major cause of earthquake damage. Landslides triggered by the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes were responsible for destroying or damaging numerous homes and other structures, blocking major transportation corridors, and damaging various types of life-line infrastructure. Typically, areas most susceptible to earthquake-induced landslides are on steep slopes and on or adjacent to existing landslide deposits, especially if the earth materials in these areas are composed of loose colluvial soils, or poorly cemented or highly fractured rocks. These geologic and terrain conditions exist in many parts of southern California, most notably in hilly areas already developed or currently undergoing development. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region, which includes the Redondo Beach Quadrangle.

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered primarily from a variety of outside sources; thus, the quality of the data is variable. Although the selection of data used in this evaluation was rigorous, the state of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Earthquake-generated ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. No attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Redondo Beach Quadrangle, for more information on the delineation of liquefaction zones.

Information developed in the study is presented in two parts: physiographic, and geologic conditions in PART I, and ground shaking opportunity, landslide hazard potential and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The onshore portion of the Redondo Beach Quadrangle covers an area of about 13 square miles in southwestern Los Angeles County. The low-lying topography in the northeastern corner includes parts of the coastal cities of Hermosa Beach, Manhattan Beach, Redondo Beach and Torrance. The southeastern corner of the map includes the western portion of the Palos Verdes Peninsula where parts of the cities of Palos Verdes Estates, Rancho Palos Verdes, and Rolling Hills Estates are located.

The Redondo Beach Quadrangle lies within the southwestern part of the Los Angeles Basin. The topography of the elevated Palos Verdes Peninsula is characterized by a series of stair step-like Pleistocene wave-cut marine terraces that are generally covered by a non-marine veneer over thin marine terrace deposits. Alluvium and slope wash deposits occur within the major drainages in some areas. A strip of ancient coastal dunes parallels the modern beach along the coastline north of the peninsula. Elevations range from sea level to about 1200 feet near the crest of the Palos Verdes Hills in the south half of the quadrangle

Access along the northern coastal section of the quadrangle is provided by Pacific Coast Highway (State Highway 1). Palos Verdes Drive and Hawthorne Boulevard provide access on the Palos Verdes Peninsula.

GEOLOGIC CONDITIONS

Surface and Bedrock Geology

For the Redondo Beach Quadrangle, bedrock geologic mapping at a scale of 1:24,000 has been published by Woodring and others (1946). Cleveland (1976) also published geologic maps covering portions of the Palos Verdes Hills at 1:12,000 scale. These sources were compiled, digitized and presented at 1:100,000 scale in Bezore and others (unpublished). This digitized compilation formed the basis of the geologic map used in this investigation.. The northern section of coastal alluvium and dunes was taken from Tinsley and others (1985). The digital geologic map was modified to reflect the most recent mapping in the area and to include interpretations of observations made during the aerial photograph landslide inventory and field reconnaissance. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of slope failures was noted.

The bedrock geologic units mapped within the Redondo Beach Quadrangle include the Monterey Formation (Tm) and its three members -- Malaga Mudstone (Tmal), Valmonte

Diatomite (Tmv), and Altimira Shale (Tma); the San Pedro Formation (Qsp); and intrusive basalt (Tb). Quaternary units include marine and non-marine terrace deposits (Qter), talus deposits (Qtb), beach sand (Qm/a), dune deposits (Qe), landslide deposits (Qls) and artificial fill (af).

Most of the upland area of the Palos Verdes Hills is underlain by the middle to upper Miocene Altimira Shale member (Tma) of the Monterey Formation, the oldest rocks exposed in the study area. The Altimira Shale consists of siliceous shale, silty and sandy shale, chert shale, chert, siltstone, bituminous shale, diatomaceous shale, diatomite, phosphatic shale, tuffaceous shale, limestone, sandstone, conglomerate, breccia and silicified limestone and shale. Intrusive basaltic rocks (Tb) occur in the lower and middle parts of the Altimira Shale member. The basaltic rocks consist of basalt, andesite, volcanic breccia and tuff breccia that forms sills that are more or less concordant with bedding. These rocks crop out along the sea cliffs from Resort Point south to Long Point. From Long Point to Abalone Cove, the basaltic rocks crop out on the south-facing slope between about elevation 200 and 700 feet. These rocks also crop out along a portion of the sea cliff and areas upslope from Bluff Cove to just north of Flatrock Point.

The upper Miocene Valmonte Diatomite member (Tmv) of the Monterey Formation overlies the Altimira Shale and underlies a portion of the crest of the Palos Verdes Hills in the central part of the uplands. This unit also crops out over a relatively small area to the east and south of Bluff Cove. The Valmonte Diatomite member overlies the Altimira Shale and consists of diatomaceous shale and diatomite. In the Torrance Quadrangle to the east, the Monterey Formation rests unconformably on pre-Cenozoic Catalina Schist, which consists of quartz-chlorite schist, quartz-sericite schist and quartz-glaucophane schist. Catalina Schist forms the basement complex beneath the entire Palos Verdes Peninsula, but is not exposed in the Redondo Beach Quadrangle.

A flight of 13 main emergent marine terraces were mapped in the Palos Verdes Hills by Woodring and others (1946), who numbered the terraces 1 through 13 in ascending order. Intermediate terraces mapped by Woodring and others (1946) include 5a, 7a. The terraces are discontinuous and not all the numbered terraces are exposed everywhere. Cleveland (1976) remapped the terrace distribution in portions of the Torrance Quadrangle and more recent work, as reported in Bryant (1982; 1987), designate several additional intermediate terraces as 2a, 2b, 3a, 3b, 4a and 4b. The wavecut platforms of the terraces are typically capped with marine sediments, a nonmarine cover, or, locally, are simply geomorphic benches without significant sedimentary cover.

Terraces 1 through 10 are exposed in the Redondo Beach Quadrangle. Terraces 1 through 5 are typically capped with upper Pleistocene to Holocene nonmarine terrace deposits (Qter) and are the only terraces shown on the geologic map. Throughout the Palos Verdes Peninsula terraces 6 through 10 have lost much, or virtually all, of their original cover through erosion. The upper Pleistocene to Holocene nonmarine terrace deposits on the lowest terraces consist of a thin marine basal strata of Palos Verdes Sand overlain by nonmarine deposits. The Palos Verdes sand is undifferentiated from the overlying nonmarine terrace deposits on the geologic map and consists of a few inches to 15 feet of calcareous sand, shell fragments and scattered small pebbles and cobbles. The overlying terrace deposits consist of poorly sorted to unsorted, crudely stratified sand, rubble and gravel. This unit is as much as 100 feet thick toward the landward part of the terrace, although the exposed thickness is generally less than 50 feet.

Holocene deposits consist of three surficial units that crop out in bands parallel to the coast, and undifferentiated alluvium along some of the stream channels. In the west, along the coast below the sea cliffs is a narrow band of modern marine beach deposits (Qm/a), consisting of arenaceous sand. The beach deposits extend from the northern boundary of the quadrangle, southward to Malaga Cove, and in Lunada Bay, east of Long Point and in Abalone Cove. To the east and inland, is a band of modern eolian dune deposits (Qe) that consist of sand and silty sand. This unit extends from the northern quadrangle boundary southward to King Harbor. Farther east and inland, are older dune deposits (Qoe) that consist of sand and silty sand. The older eolian dune deposits are more densely vegetated and, hence, more stabilized dunes than the modern dune deposits. This unit extends from the northern quadrangle boundary southward to the northern margin of the uplands and eastward to the eastern quadrangle boundary. South of King Harbor, the older eolian dunes extend from the top of the sea cliff face to the eastern quadrangle boundary. Active alluvium (Qal) is identified in scattered deposits along a few of the modern streams and is typically exposed near or just above the top of the sea cliffs. A more detailed description of the late Quaternary geologic units is presented in the liquefaction portion (Section 1) of this report.

Landslide deposits (Qls) are scattered across the quadrangle and typically occur as small to moderate size failures on the slopes of drainages and along the sea cliffs in areas underlain by the Altimira Shale. However, in the southeast corner of the quadrangle part of the large Portuguese Bend landslide complex occurs. Modern artificial fills (af) are mapped at large school sites, residential subdivisions, commercial developments, and along freeway embankments.

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, they must first be ranked on the basis of their overall shear strength. Shear strength data for the rock units identified on the geologic map were obtained from geotechnical reports prepared by consultants and on file with the local government permitting departments, (see Appendix A). The locations of rock and soil samples taken for shear testing are shown on Plate 2.1.

Shear strength data gathered from the above sources were compiled for each mapped geologic unit, which were then grouped on the basis of average angle of internal friction (average f) and lithologic character. Geologic formations that have little or no shear test information have been added to existing groups on the basis of lithologic and stratigraphic similarities.

The results of the grouping of geologic materials in the Redondo Beach Quadrangle are in Tables 2.1 and 2.2.

REDONDO BEACH QUADRANGLE
SHEAR STRENGTH GROUPINGS

	Formation Name	Number Tests	Mean phi value	Group phi Mean/Median (deg.)	Group C Mean/Median (psf)	Phi Values Used in Stability Analyses	Similar Lithology: no data
GROUP 1	Tma (fbc)	41	36.3				
	Tb	14	37.1	**36.5/35**	**680/300**	**36**	
GROUP 2	Qal	3	32				
	Qter	8	31	**31.2/32**	**394/300**	**32**	Q, Qoe, Tmal
	Tmv	2	31				
GROUP 3	af	22	26.1				
	Qtb	6	26.7	**26.2/25.5**	**493/300**	**26**	Qe, Qm/a, Qsp
GROUP 4	Tma (abc)	47	18.4	**18.4/19**	**570/400**	**18**	
GROUP 5	Qls	25	9.8	**9.8/8.5**	**307/209**	**10**	

Table 2.1. Summary of the Shear Strength Statistics for the Redondo Beach Quadrangle.

SHEAR STRENGTH GROUPS FOR THE REDONDO BEACH QUADRANGLE				
GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**	**GROUP 5**
Tma (fbc)	Q	af	Tma (abc)	Qls
Tb	Qal	Qe		
	Qoe	Qm/a		
	Qter	Qsp		
	Tmal	Qtb		
	Tmv			

Table 2.2. Summary of the Shear Strength Groups for the Redondo Beach Quadrangle.

Structural Geology

The geologic structure of the Palos Verdes Peninsula is dominated by the Palos Verdes Fault and a large, broad northwest-southeast-trending doubly plunging anticline (Ehlig, 1982a; 1982b), (Bryant, 1987), (Yerkes and others, 1965) and (Rowell, 1982). The anticlinal form of the peninsula has been uplifted as a horst between the Palos Verdes fault on the northeast and faults on the sea floor to the southwest. The Palos Verdes Fault is a steep, southwest-dipping reverse fault, upthrown on the southwest, that is exposed along the northeast margin of the Palos Verdes Hills and separates the upland area from the flatlands of the Central Plain of the Los Angeles Basin on the northeast. The axis of the anticline forms a concave-to-the-south arc from the northwest corner of the Palos Verdes Peninsula, in the area of Flatrock Point, extending toward the southeast to the vicinity of Whites Point (east of the Redondo Beach Quadrangle). In most places within the anticline the strata are tilted less than 20 degrees.

Other faults and small folds are also present in the Redondo Beach Quadrangle. Woodring and others (1946) mapped a number of other structures, the trends of which change systematically from north to south. In the northwestern corner of the Palos Verdes Peninsula, along the coast at, and inland of, Flatrock Point and Bluff Cove Woodring and others, 1946) mapped two southwest-trending synclines, the southernmost of which was mapped as discontinuous and may be two separate synclines, and one southwest-trending anticline between the synclines. An east-west-trending syncline, on the north, and anticline, on the south, were mapped to the east of Palos Verdes Point. Two synclines, the northern one of which was mapped as discontinuous and may represent two separate synclines, and one anticline were mapped in the southwestern of the Palos Verdes Peninsula, in the area east of Lunada Bay and north of Abalone Cove. These folds are likely undulations in the general anticlinal structure of the Palos Verdes Peninsula.

Bedding in the geologic units strikes approximately parallel to the trend of the structures with dips that range between 5 and 55 degrees.

We used structural strike and dip information from previous geologic mapping by Woodring and others (1946) and Cleveland (1976) to categorize areas of common stratigraphic dip direction and magnitude, similar to the method presented by Brabb (1983). The dip direction category was compared to the slope aspect (direction) category and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category, and the bedding dip was greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area. This information was then used to subdivide mapped geologic units into areas where fine-grained and coarse-grained rock strengths would be used.

Landslide Inventory

The evaluation of earthquake-induced landsliding requires an up-to-date and complete picture of the previous occurrence of landsliding. An inventory of the existing landslides in the entire Redondo Beach Quadrangle was prepared using interpretation of stereo pairs of aerial photographs of the study area and limited field reconnaissance (Haydon, unpublished). All areas containing landslides identified in the previous work of Woodring and others (1946),Cleveland (1976), Ehlig, (1982a and b;1987), Lass, and Eagen, (1982), Scullin, (1987), and Anderson (1987) where re-evaluated during the aerial photograph interpretation conducted for this investigation. Some of the landslides identified in the previous work were not included in the landslide inventory because in our reevaluation it was concluded the feature was not a landslide, while many additional landslides were identified and the boundaries of many of the landslides were modified from the previous work.

The completed hand-drawn landslide map was scanned, digitized and the database was attributed with landslide information on confidence of interpretation (definite, probable, or questionable) and other properties, such as activity, thickness, and associated geologic unit(s). To keep the landslide inventories of consistent quality, all landslides originally depicted on the digitized geologic map were deleted and only those included in the DMG inventory were incorporated into the hazard-evaluation process. A version of this landslide inventory is included with Plate 2.1.

PART II

EARTHQUAKE-INDUCED LANDSLIDE GROUND SHAKING OPPORTUNITY

Design Strong-Motion

The Newmark analysis used in delineating the earthquake-induced landslide zones requires the selection of a design earthquake strong-motion record. For the Redondo Beach Quadrangle, the selection was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996; Cramer and Petersen, 1996). The parameters used in the record selection are:

Modal Magnitude:	7.0 to 7.1
Modal Distance:	2.5 to 12.6 km
PGA:	0.33 to 0.51 g

The strong-motion record selected was the Channel 3 (N35°E horizontal component) University of Southern California Station #14 recording from the magnitude 6.7 Northridge Earthquake (Trifunac and others, 1994). This record had a source to recording site distance of 8.5 km and a PGA of 0.59 g. The selected strong-motion record was not scaled or otherwise modified prior to analysis.

Displacement Calculation

To develop a relationship between the yield acceleration (a_y; defined as the horizontal ground acceleration required to cause the factor of safety to equal 1.0) and Newmark displacements, the design strong-motion record was integrated twice for a given a_y to find the corresponding displacement, and the process repeated for a range of a_y (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for any combination of geologic material strength and slope angle, as represented by the yield acceleration. We used displacements of 30, 15 and 5 cm as criteria for rating levels of earthquake shaking damage on the basis of the work of Youd (1980), Wilson and Keefer (1983), and the DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.076, 0.129 and 0.232 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant to the Redondo Beach Quadrangle.

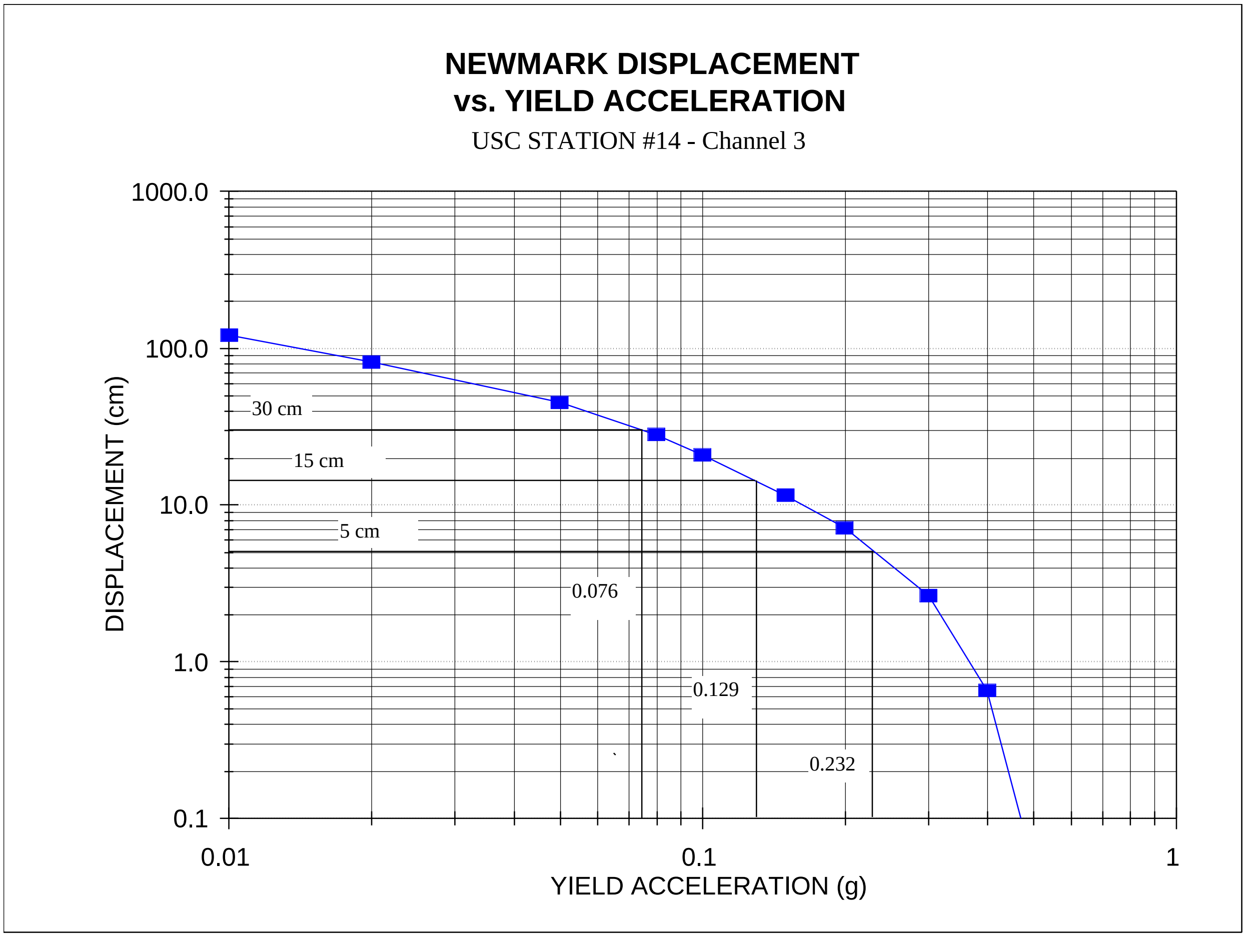

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station # 14 Strong-Motion Record from the 17 January 1994 Northridge, California Earthquake.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Terrain Data

The calculation of slope gradient is an essential part of evaluating slope stability under earthquake conditions. To calculate slope gradient for the terrain within the Redondo Beach Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the U.S. Geological Survey. This DEM has a 10-m horizontal resolution and a 7.5-m vertical accuracy (USGS, 1993) and was prepared from topographic contours based on 1963 photographs.

Areas that have undergone large-scale grading since 1963 as part of residential development were identified on 1: 40,000-scale aerial photography flown in 1994 and 1995 (NAPP, 1994). Photogrammetric DEM's covering the graded areas were prepared by the U.S. Bureau of Reclamation with ground control points established by DMG. The photogrammetric DEM's were then merged into the USGS DEM, replacing the areas of out-dated elevation data. Surrounding quadrangle DEM's were merged with the Redondo Beach DEM to avoid the loss of data at the quadrangle edges when the slope calculations were performed. Plate 2.1 shows those areas where the topography is updated to1994 grading conditions.

Slope-gradient maps were made from both sets of DEM's using a third-order finite-difference center-weighted algorithm (Horn, 1981). The slope-gradient map was used in conjunction with the geologic strength map to prepare the earthquake-induced landslide hazard potential map.

Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield acceleration calculated by Newmark's equations represents the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. The acceleration values were compared with the ground shaking opportunity, defined by Figure 2.1, to determine the earthquake-induced landslide hazard potential. Based on the criteria described in Figure 2.1 above, if the calculated yield acceleration was less than 0.076g, expected displacements could be greater than 30 cm, and a HIGH (H on Table 2.3) hazard potential was assigned. Likewise, if the calculated a_y fell between 0.076 and 0.129g a MODERATE (M on Table 2.3) potential was assigned, between 0.129 and 0.232 a LOW (L on Table 2.3) potential was assigned, and if a_y were greater than 0.232g a VERY LOW (VL on Table 2.3) potential was assigned.

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

REDONDO BEACH QUADRANGLE
HAZARD POTENTIAL MATRIX

Geologic Material Group	Mean Phi	SLOPE CATEGORY (percent) I 0-5	II 6-9	III 10-19	IV 20-23	V 24-35	VI 36-37	VII 38-41	VIII 42-46	IX 47-48	X 49-54	XI 55-59	XII 60-64	XIII >64
1	36	VL	VL	VL	VL	VL	VL	VL	VL	L	L	L	M	H
2	32	VL	VL	VL	VL	VL	VL	L	L	L	M	H	H	H
3	26	VL	VL	VL	VL	L	M	M	H	H	H	H	H	H
4	18	VL	VL	L	M	H	H	H	H	H	H	H	H	H
5	10	L	M	H	H	H	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Redondo Beach Quadrangle. Shaded area indicates hazard potential levels included in the hazard zone.

EARTHQUAKE-INDUCED LANDSLIDE ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (in press). Under those criteria, earthquake-induced landslide zones are areas meeting one or more of the following:

1. Areas known to have experienced earthquake-induced slope failure during historic earthquakes.

2. Areas identified as having past landslide movement, including both landslide deposits and source areas.

3. Areas where CDMG's analyses of geologic and geotechnical data indicate that the geologic materials are susceptible to earthquake-induced slope failure.

Existing Landslides

Studies of the types of landslides caused by earthquakes (Keefer, 1984) show that re-activation of the whole mass of deep-seated landslide deposits is rare. However, it has been observed that the steep scarps and toe areas of existing landslides, which formed as a result of previous landslide movement, are particularly susceptible to earthquake-induced slope failure. In addition, because they have been disrupted during landslide movement, landslide deposits are inferred to be weaker than coherent, undisturbed, adjacent source rocks. Finally, we felt that a long duration, San Andreas fault-type earthquake could be capable of initiating renewed movement in existing deep-seated landslide deposits. Therefore, all existing landslides identified in the inventory with a definite or probable confidence of interpretation were included in the hazard zone.

Geologic and Geotechnical Analysis

On the basis of a DMG pilot study (McCrink and Real, 1996) the earthquake-induced landslide zone includes all areas determined to lie within the High, Moderate and Low levels of hazard potential. Therefore, as shown in Table 2.3, geologic material strength group 5 is always included in the zone, strength group 4 is in the zone for all slopes greater than 9%, strength group 3 above 23%, strength group 2 above 37% and strength group 1, the strongest rock types, were zoned for slope gradients above 46%. This results in roughly 10% of the land (1,040 acres) in the Redondo Beach Quadrangle lying within the earthquake-induced landslide zone.

ACKNOWLEDGMENTS

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plotted the graphic displays associated with the earthquake-induced landslide zone map, and Lisa Chisholm prepared the landslide attribute tables for input into this report.

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APPENDIX A
SOURCES OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Division of Mines and Geology, Environmental Impacts Reports File	**64**
City of Rancho Palos Verdes, Planning Department	**27**
County of Los Angeles, Department of Public Works, Materials Engineering Division	**77**
Total number of tests used to characterize the units in the Redondo Beach Quadrangle	**168**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Redondo Beach 7.5-Minute Quadrangle, Los Angeles County, California

By

Mark D. Petersen, Chris H. Cramer, Geoffrey A. Faneros, Charles R. Real, and Michael S. Reichle

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included, are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the “Simple Prescribed Parameter Value” method (SPPV) described in the site investigation guidelines (California State Mining and Geology Board, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 2 and 3, addressing liquefaction and earthquake-induced landslide hazards, constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on DMG’s Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the seismogenic sources as published in the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

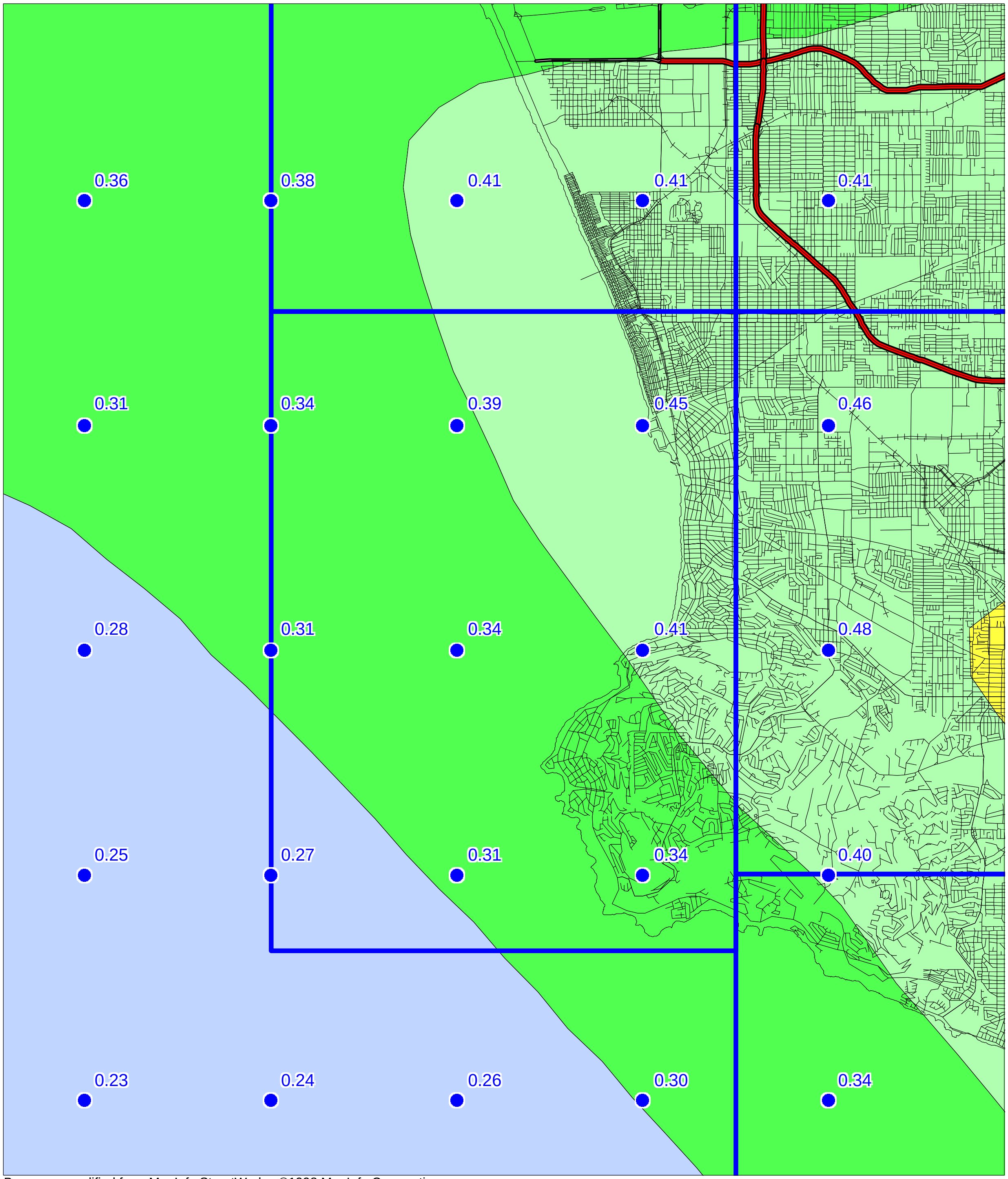
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent

REDONDO BEACH 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

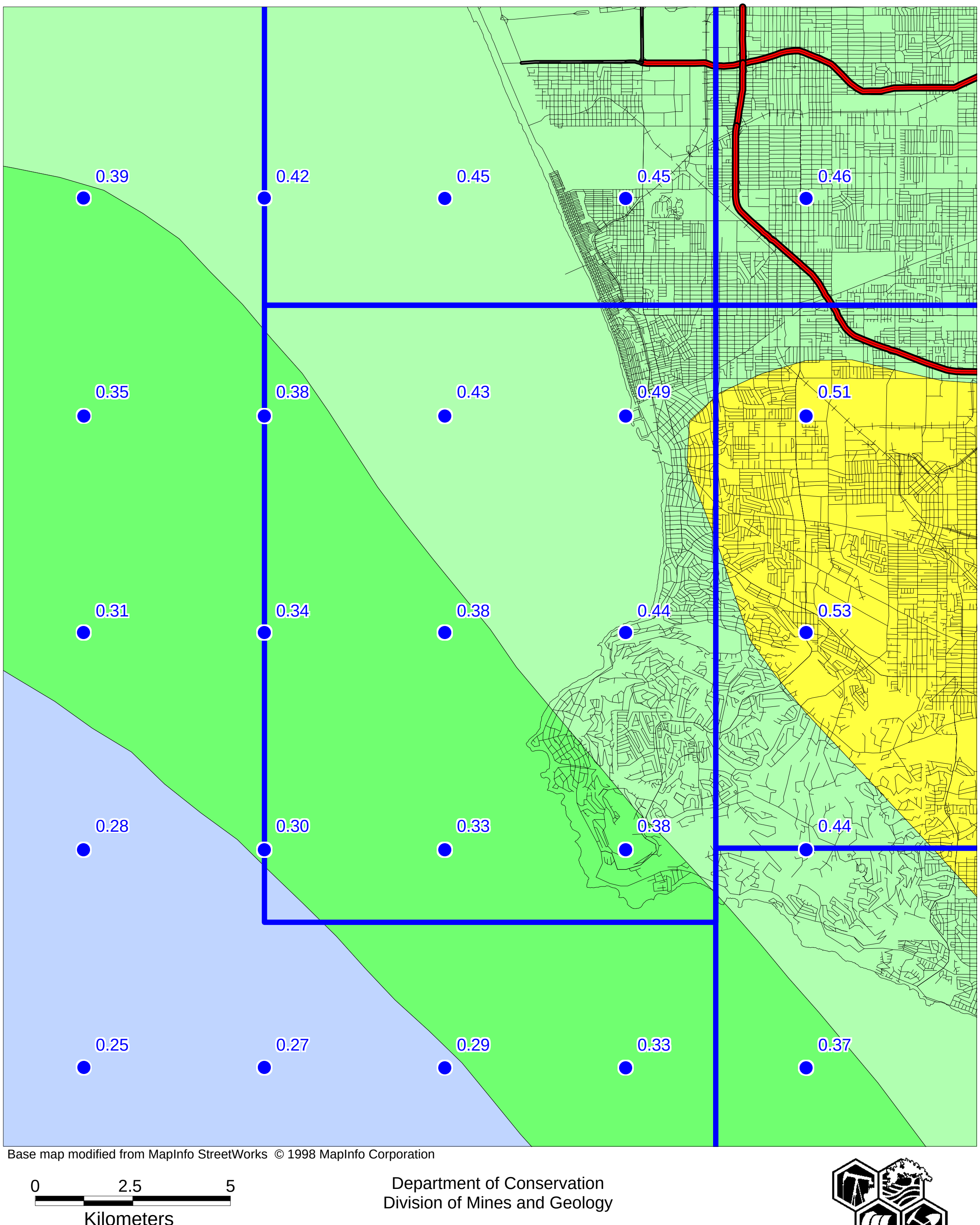
Figure 3.1

REDONDO BEACH 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Department of Conservation
Division of Mines and Geology

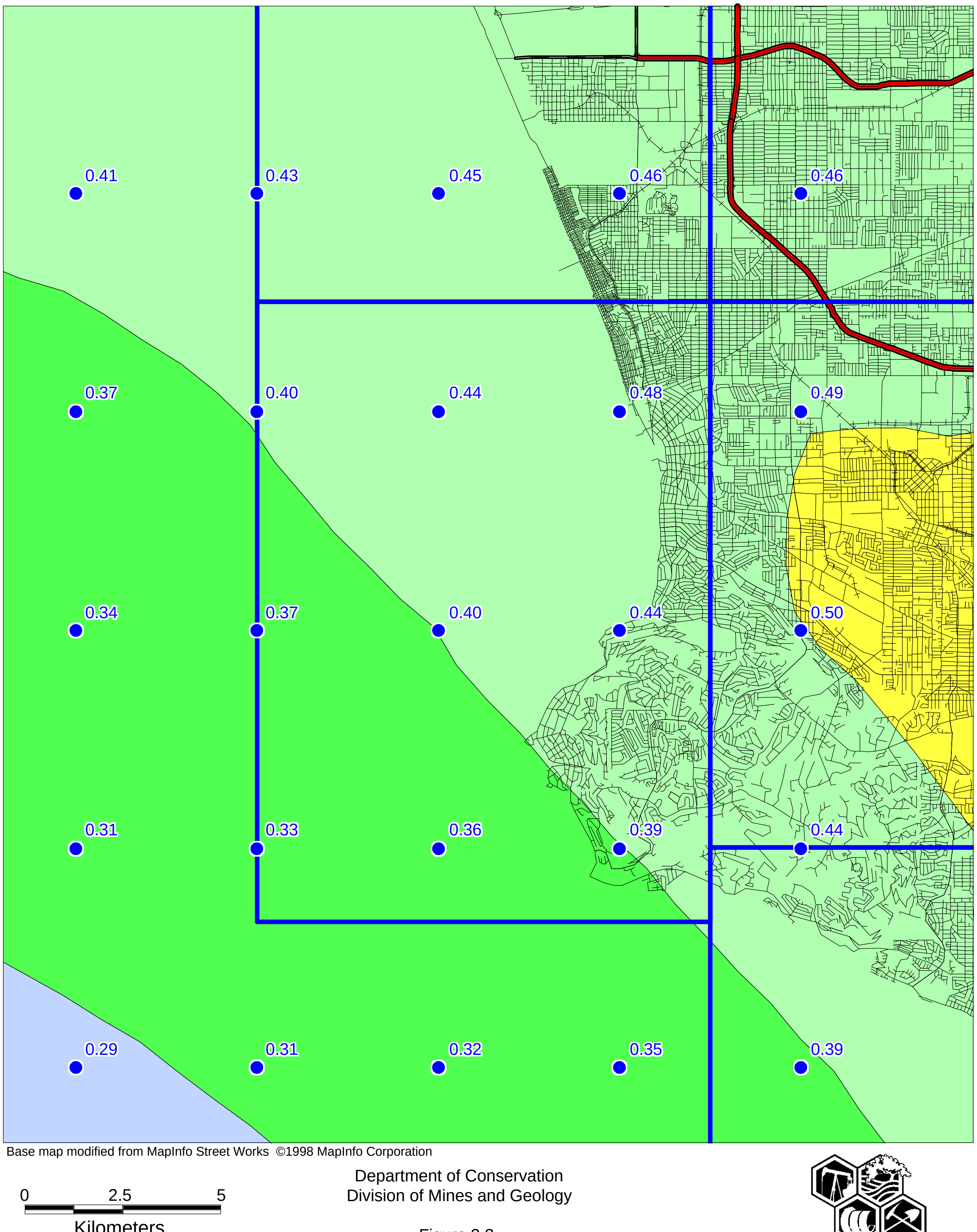
Figure 3.2

REDONDO BEACH 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works ©1998 MapInfo Corporation

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Figure 3.3

quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation

REDONDO BEACH 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

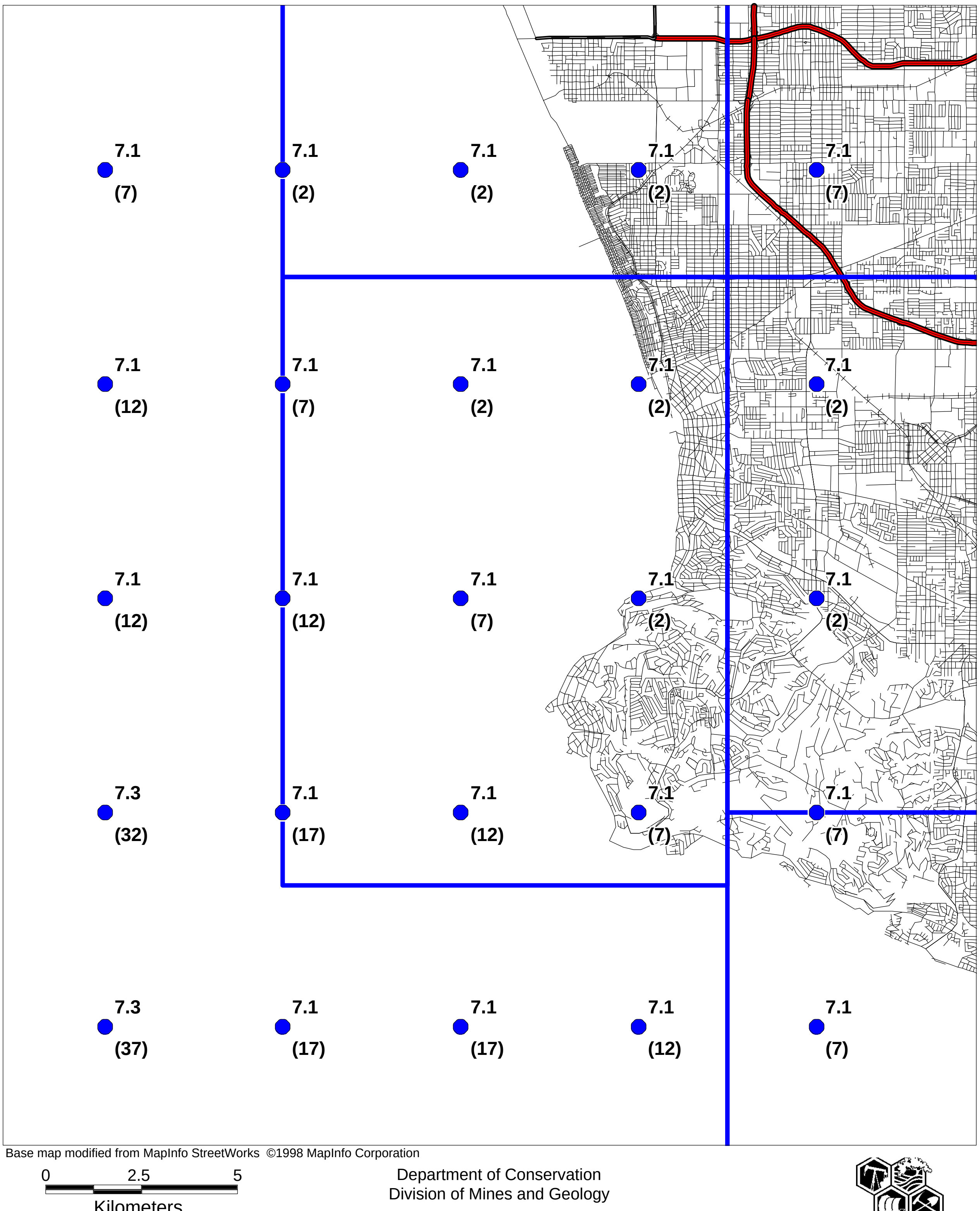
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)

(Distance (km))



Department of Conservation
Division of Mines and Geology

Figure 3.4

of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not previously been recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (California State Mining and Geology Board, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the “importance” or sensitivity of the proposed building with regard to occupant safety.

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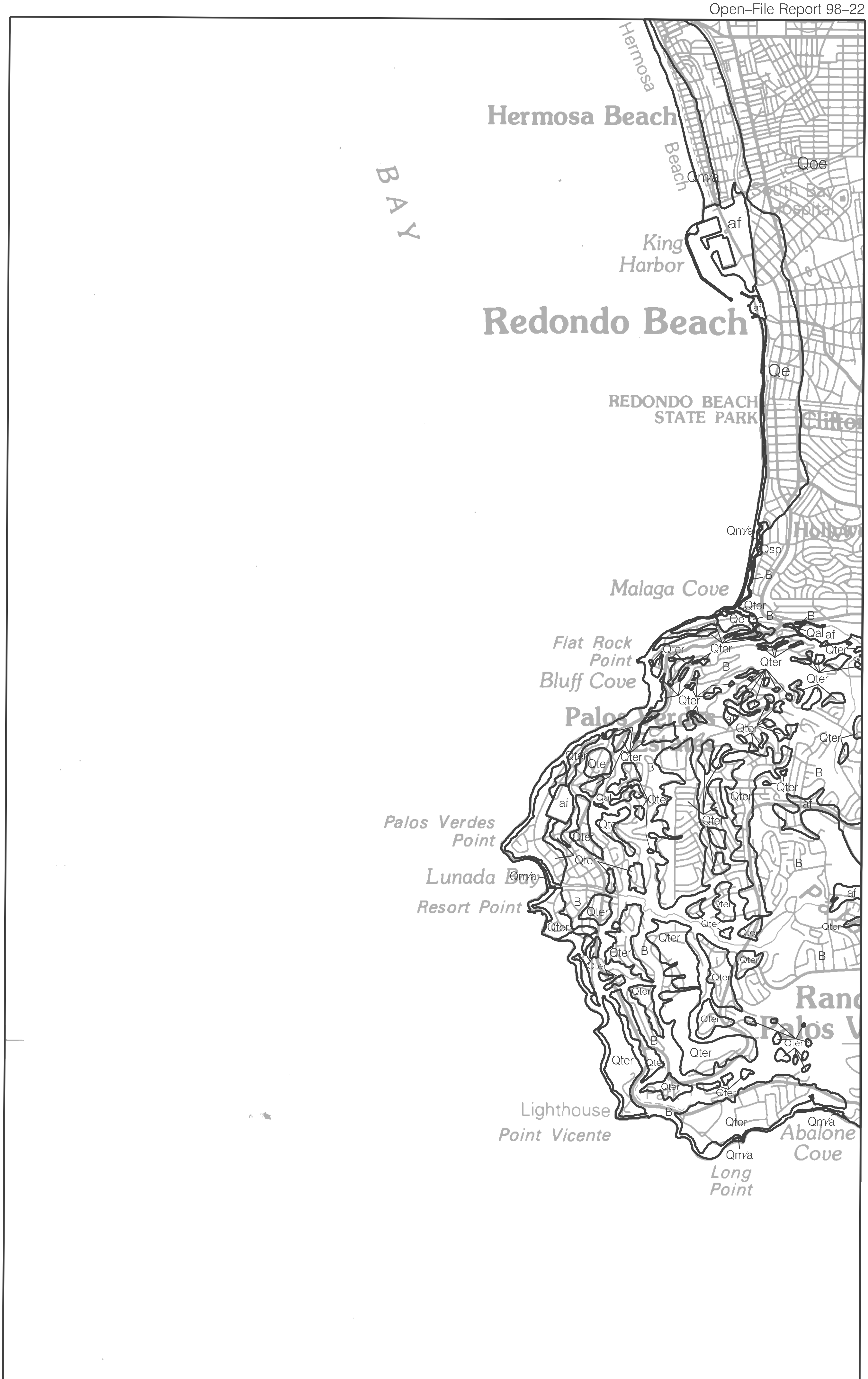
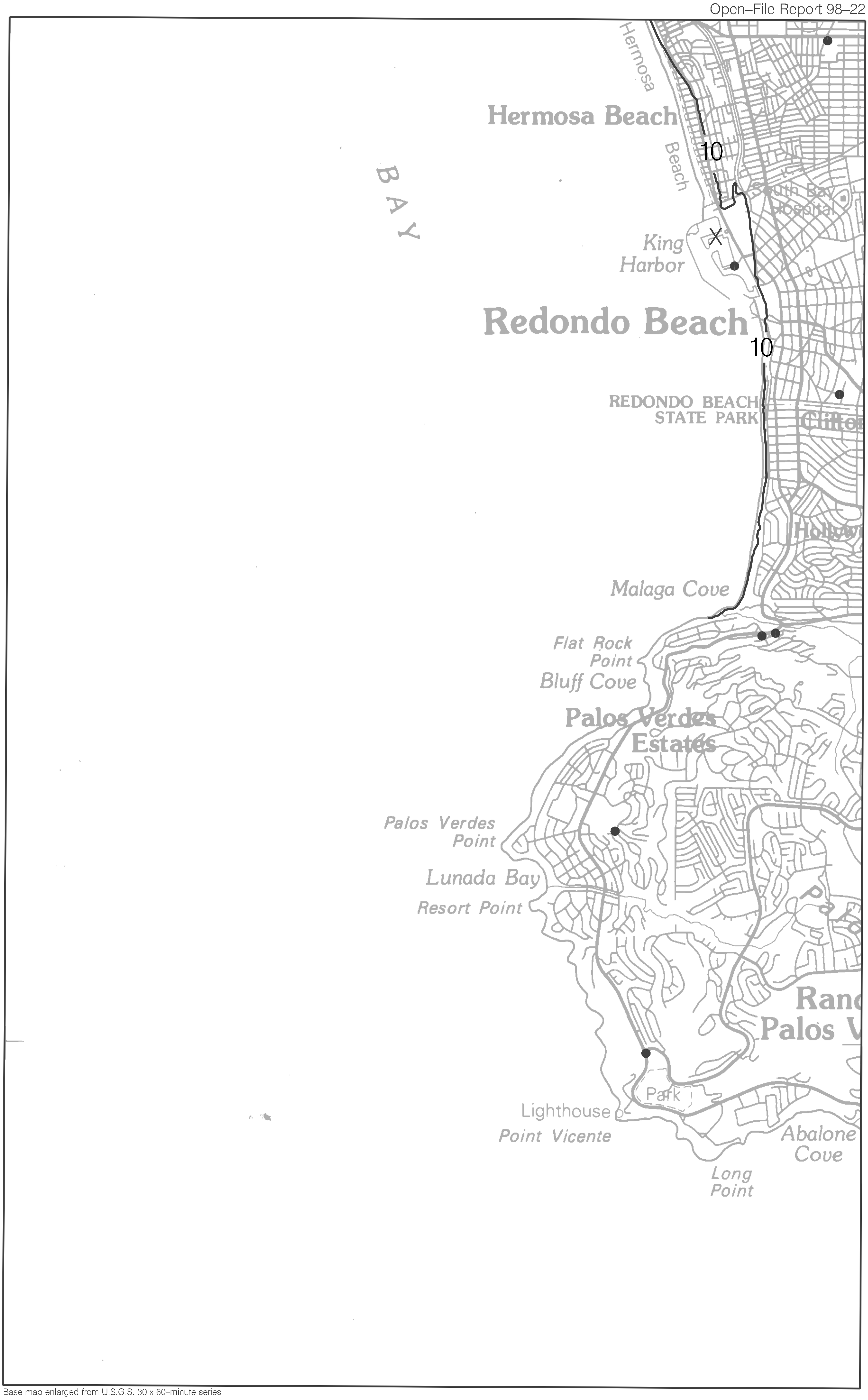


Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 1.1 Quaternary Geologic Map of the Redondo Beach Quadrangle.
See Geologic Conditions section in report for descriptions of the units.
B = Pre–Quaternary bedrock.

ONE MILE
SCALE



Base map enlarged from U.S.G.S. 30 x 60–minute series

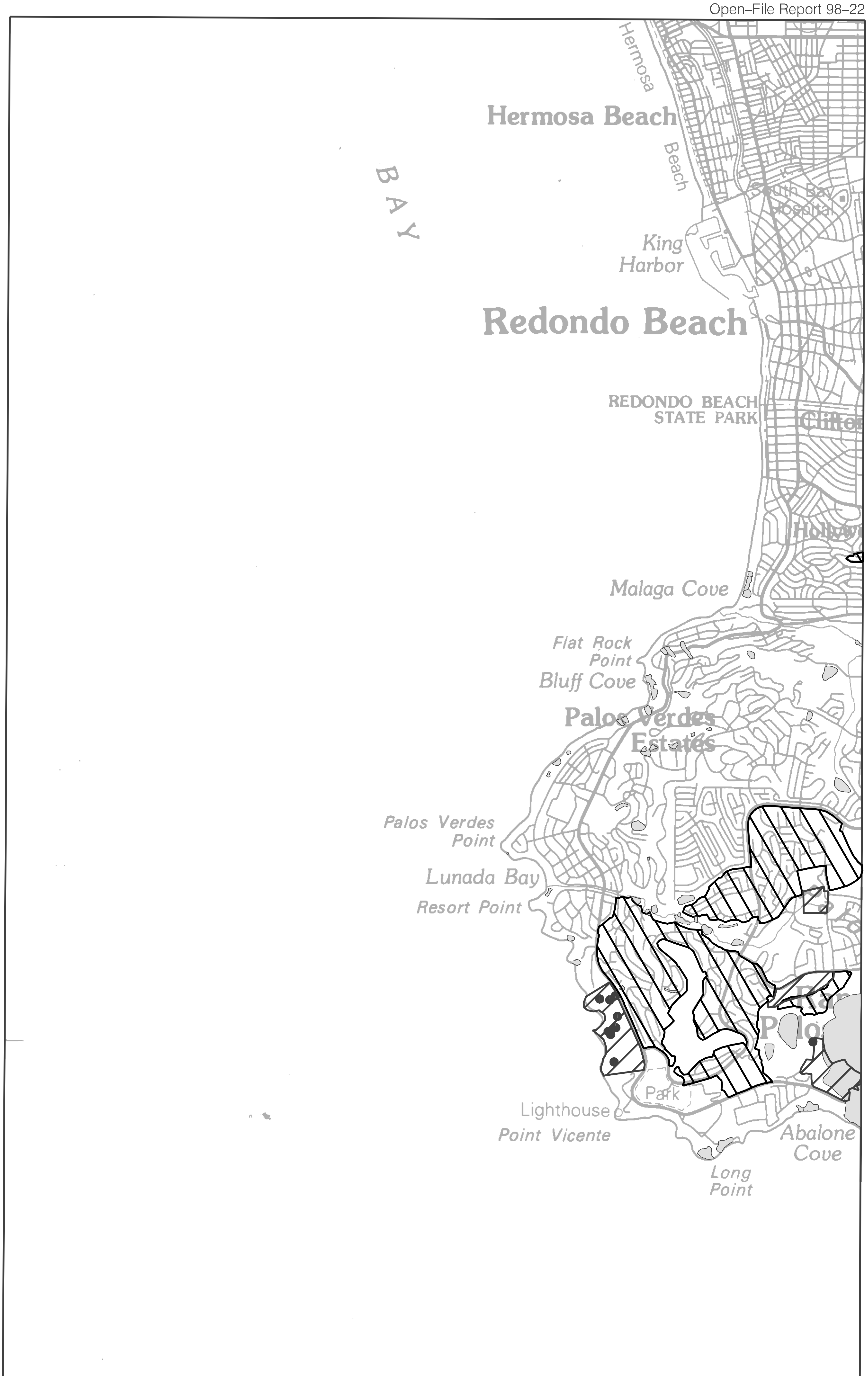
Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Redondo Beach Quadrangle.

● Borehole Site — 30 — Depth to ground water in feet

X Site of historical earthquake–generated liquefaction. See "Areas of Past Liquefaction" discussion in text.

ONE MILE

SCALE



Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 2.1 Landslide inventory, Shear Test Sample Locations, and Areas of Significant Grading, Redondo Beach Quadrangle.